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ORIGINAL ARTICLE

Dynamic response of woody vegetation on fencing protection in semi-arid areas; Case study: Pilot exclosure on the Firmihin Plateau, Socotra Island

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Abstract Woody vegetation dynamics and *Dracaena cinnabari* regeneration have been studied for five years in the conditions of Socotra Island. Woody plants were measured regularly inside and outside the exclosure area, and the growth and survival of *D. cinnabari* seedlings were observed. In the exclosure of about 1000 m^2 a total of 49 species were identified, including 23 endemics, growing in the average density of 3.82 specimens per m^2. The fenced area was overgrown relatively rapidly by dense grass cover – reaching approx. 2.7 t/ha. Species growth dynamics inside and outside the exclosure shows that grazing had a marked impact, leading to the elimination of trees and shrubs. All grazed species grew noticeably in the exclosure, in the average of 50 cm in 5 years. *D. cinnabari* as the dominant flagship species of Socotra has been studied with regards to regeneration dynamics. Observations indicate that probability of its seedlings survival increases with their age. No seedlings germinated from the seeds sown in the experiment, however, outplanted seedlings performed relatively well. Field observations show that *D. cinnabari* seed germination is triggered when the seed reaches a protected micro-habitat with a developed humus layer and high relative humidity in the soil lasts for at least two days.

1. Introduction

In arid regions where the land is unsuitable for any other agricultural practices, extensive grazing is often the only source of food for local communities. Not only present tropical regions but particularly cultural landscapes of Europe and North America have been faced to profound changes related to high demand for wood and to extensive livestock husbandry. Especially animal browsing had shaped nearly all coastal areas of the ancient world, including Mediterranean reigns (ancient

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Greece, Illyria and Rome), the inland of early mediaeval British kingdoms and lordships (England, Ireland, Scotland, Wales) and "low countries" of northern Europe (Flanders, Nederlands). Astonishingly, forest cover as low as 4–9% is perceived there after a few centuries as the eternal landscape status.

Socotra Island is an example of a site influenced for centuries by human-livestock interaction. The island has been inhabited for 3000 years (Cerny et al., 2009) by the descendants of a South Arabian language group within the Semitic language family (Morris, 2002). The main way of the livelihood of local inhabitants is extensively practised transhuman pastoralism and to a lesser extent also fishing. Grazing practices have influenced plant communities and contributed significantly to the contemporary distribution and structure of woody populations around the island (Van Damme and Banfield, 2011), including endemic *Commiphora* spp., *Boswellia* spp., *Dendrosicyos socotrana*, *Dracaena cinnabari* (by some authors "the dragon's blood tree") and other trees. As a result, the most extensive vegetation type is presently low grazed shrubland dominated by *Euphorbiaceae* (e.g., *Jatropha unicostata*), species unpalatable to livestock.

The charismatic *D. cinnabari* groves contribute significantly to the island's biodiversity and have dominated Socotra's landscape for millennia, from 250 m a.s.l. up to the highest areas of the mountains. In the past, the third altitudinal vegetation zone on Socotra (Habrova, 2004) was characterised by the presence of *D. cinnabari* forests and woodlands. However, its current presence (Kral and Pavlis, 2006; Brown and Mies, 2012; De Sanctis et al., 2013) is limited to sites with lower grazing impact. As a result of intensive grazing, pastures and low/dwarf shrubland with *Croton socotranus* and/or *Buxanthus pedicellatus* predominate (Habrova and Bucek, 2010).

Experimental exclosures (Aerts et al., 2009) are often used as treatments to exclude (or statistically control for) the effects of herbivory on species richness and recruitment in plant communities. Based on many scientific discussions (e.g., Adolt et al., 2012; Adolt and Pavlis, 2004; Attorre et al., 2007; Habrova et al., 2009; Hubalkova, 2011; Scholte and De Geest, 2010 etc.), essential research question has been raised to answer if flagship *D. cinnabari* can spontaneously regenerate when its seedlings are protected from grazing pressure. Because fenced areas furnish excellent reference plots for interpreting the effect of grazing on vegetation dynamics, an experimental exclosure was established in 2000 on the southwest slope of the Firmihin Plateau. The development of the vegetation in the absence of grazing in this exclosure was studied every year until 2004, when the fence was unfortunately destroyed.

The objective of further described research has been aspiring to settle three hypotheses. First simple one was related to the common expectation that exclosure establishment triggers dynamic growth of plants. Second hypothesis has been built around the anticipation that outplanted *D. cinnabari* seedlings are able to survive droughts much better if being fenced against ruminants and their grazing pressure. Third hypothesis has been related to the *D. cinnabari* seed germination performance in the wild.

2. Materials and methods

2.1. Study area

Socotra Island (3600 km^2, 12°19′–12°42′ N latitude and 53°18′–54°32′ E longitude) is located in an arid tropical region. The climate is dry and hot, with average temperatures ranging between 28 °C on the coast and 18 °C in the mountains (Habrova, 2007; Scholte and De Geest, 2010). The estimated total annual precipitation is less than 200 mm (Scholte and De Geest, 2010) on the coast and, most likely, up to 1000 mm at an elevation of 1000 m a.s.l. (Adolt and Pavlis, 2004). Horizontal precipitation plays a very important role in the mountain region.

Socotra is biologically unique and is marked by a high level of biodiversity. A total of 37% of Socotra's plant species are endemics (Miller et al., 2004), which is the result of the island's long-term separation from the African continent. The Socotra Archipelago was declared a UNESCO Biosphere Reserve in 2003, inscribed among Natural properties on UNESCO's World Heritage List in 2008, and designated as one of the 'Global 200' priority natural habitats by WWF.

One of the most interesting places on Socotra is the Firmihin Plateau (between 54°00′18″–54°02′20″ E and 12°28′07″–12°31′53″ N, 400–750 m a.s.l.). This locality represents the medium-steep lands (slopes approx. 5–10°) of the limestone plateaus on the southern part of the island. It is exposed to the summer monsoon and it is the location of the densest *D. cinnabari* forest (Kral and Pavlis, 2006) on the island. It is surrounded by deep canyons and contains no permanent watercourses. Human settlements are present only on the northern and southern borders of the area. Most likely, the region has only recently been colonised and it is used extensively as a pastureland. The annual mean temperature on the Firmihin Plateau is 23.4 °C. The daily mean temperatures range between 20 °C in February and 29 °C in May. The minimum temperature recorded on the plateau was 14.35 °C, and the maximum was 36.26 °C (Culek et al., 2006). The annual precipitation reaches 343 mm (Habrova, 2007). The undergrowth is rather sparse, with approximately 20–30% cover.

2.2. Vegetation dynamics

The dynamics of the woody vegetation was studied in the experimental exclosure, and also in a neighbouring reference (not fenced) plot established in a wild area on the southwest side of the Firmihin Plateau at an approximate altitude of 440 m. Annual investigations of the plant dynamics under natural conditions and in the absence of grazing pressure were conducted from 2000 through 2004. The exclosure site is situated on the dividing line between the second and the third altitudinal vegetation zones (Habrova, 2004). The characteristics of the soil and the climatic features are generally the same in all parts of the Firmihin Plateau except that the density of trees is lower in the southern part.

The exclosure size was approximately 33 × 34 m; its area was greater than 1000 m^2. Its borders were protected against grazing by a 1.8 m stone wall. Table 1 shows the central rectangle of the exclosure (from square No. 1 to square No. 42), which was composed of 4 × 4 m squares. The external margins of the plot (square Nos. 50–79) had rather irregular shapes due to terrain features. The research plot was fenced in February 2000, and a detailed inventory of the vegetation was conducted in October 2000, September 2001, August 2002, June 2003, November 2003 and April 2004. The total height of all woody species was regularly recorded from 2000 through 2004. It is further presented in the results section – see Tables 2 and 3,

Table 1 Design and order of the 4 × 4 m squares inside the experimental plot.

50	51	52	53	54	55	56	57	58
59	1	2	3	4	5	6	7	60
61	8	9	10	11	12	13	14	62
63	15	16	17	18	19	20	21	64
65	22	23	24	25	26	27	28	66
67	29	30	31	32	33	34	35	68
69	36	37	38	39	40	41	42	70
71	72	73	74	75	76	77	78	79

covering mean heights and their standard deviations (see Fig. 1).

As woody species, we considered in a broader sense not only trees (e.g., *Ziziphus spina-christi*), shrubs (e.g., *Lycium sokotranum*) and semi-shrubs (e.g., *Withania* spp.) but also perennial woody herbs (e.g., *Aerva* spp.) that were present and visible in both the humid and dry seasons. The precise position of all identified woody plants was recorded in terms of an *x*- and *y*-axis location to represent the positions graphically. The data visualisation was performed with Stand Visualization System (SVS) software (USDA Forest Service, Pacific Northwest Research Station, Fig. 2). Besides woody species inventory, dry biomass of herbaceous plants was estimated using the common destructive method.

In order to define a reference area to facilitate comparisons with the dynamics of the woody vegetation inside the exclosure, a second square was established on the eastern edge of the site, outside of the exclosure, in 2002. The woody vegetation of this outer square (33 × 33 m) was analysed, but unpalatable species (e.g., *J. unicostata*, *Withania* spp.) were not considered because they are not influenced by ruminants.

2.3. *D. cinnabari* regeneration

In both, the exclosure site and the control site, dynamics of *Dracaena* seedlings growth has been observed. Direct sowing and seedlings planting in both plots have been applied. A total of 200 seeds were sown inside and outside the exclosure in the year 2000. Within the exclosure six main squares (27, 28, 34, 35, 41 and 42) had been chosen to record any individual that germinated and survived. The seeds were sown near adult *D. cinnabari* trees to benefit from their shade. Moreover, two sets of 30 *D. cinnabari* seedlings were experimentally planted between 2001 and 2003 at regular intervals in suitable places inside and also outside the exclosure, and their survival was monitored.

3. Results

3.1. The dynamics of woody vegetation without grazing pressure

A total of 49 species, including herbs, were found within the exclosure plot. Of these species, 23 are considered endemic. The herbaceous endemics were *Convolvulus hildebrandtii, Corchorus erodioides, Crotalaria strigulosa*, *Dicliptera effusa*, *Echidnopsis bentii*, *Erucastrum rostratum*, *Helichrysum balfourii*, *Melhania milleri*, *Pulicaria diversifolia* and *Rhinacanthus scoparius*.

In total, 22 woody species were detected (from 382 individuals in Table 2) inside the exclosure. Of these, the following were Socotran endemic species: *Barleria tetracantha, Carphalea obovata*, *Commicarpus heimerlii, C. socotranus*, *Cryptolepis intricata*, *D. cinnabari*, *Heliotropium nigricans, J. unicostata*, *L. sokotranum*, *Ochradenus socotranus*, *Rhus thyrsiflora*, *Trichocalyx orbiculatus* and *Withania riebeckii.*

The tallest species in the exclosure (except *D. cinnabari* with 10.7 m) were as follows: *Ziziphus spina-christi* (max. measured height 400 cm), *T. orbiculatus* (330 cm), *J. unicostata* (290 cm), *L. sokotranum* (240 cm), *C. socotranus* (230 cm) and *Flueggea leucopyrus* (230 cm).

Certain species showed a positive response to the termination of grazing (i.e., *Grewia erythraea*, *B. tetracantha*, *Aerva lanata*), whereas others responded rather negatively (*W. riebeckii*, *L. sokotranum*).

The greatest increment in height was especially evident in the species that showed the strongest negative effects of grazing (e.g., *T. orbiculatus, C. intricata*, *F. leucopyrus*). The maximum increment was achieved by a shrub, *T. orbiculatus* – up to 47.5 cm. In contrast, the increments for certain species, such as *W. riebeckii* and *J. unicostata*, were (given their total height) rather minimal or even negative.

On average, 4.19 woody species occurred per square (4 × 4 m), i.e., 3.82 m^2 corresponded to one woody species. The largest number of woody species occurred in the northern

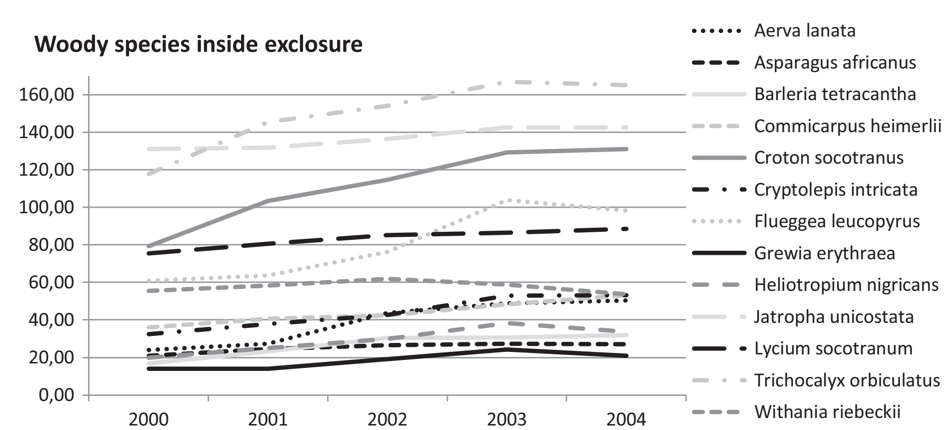

Figure 1 Graphic expression of mean increment of woody species in individual years.

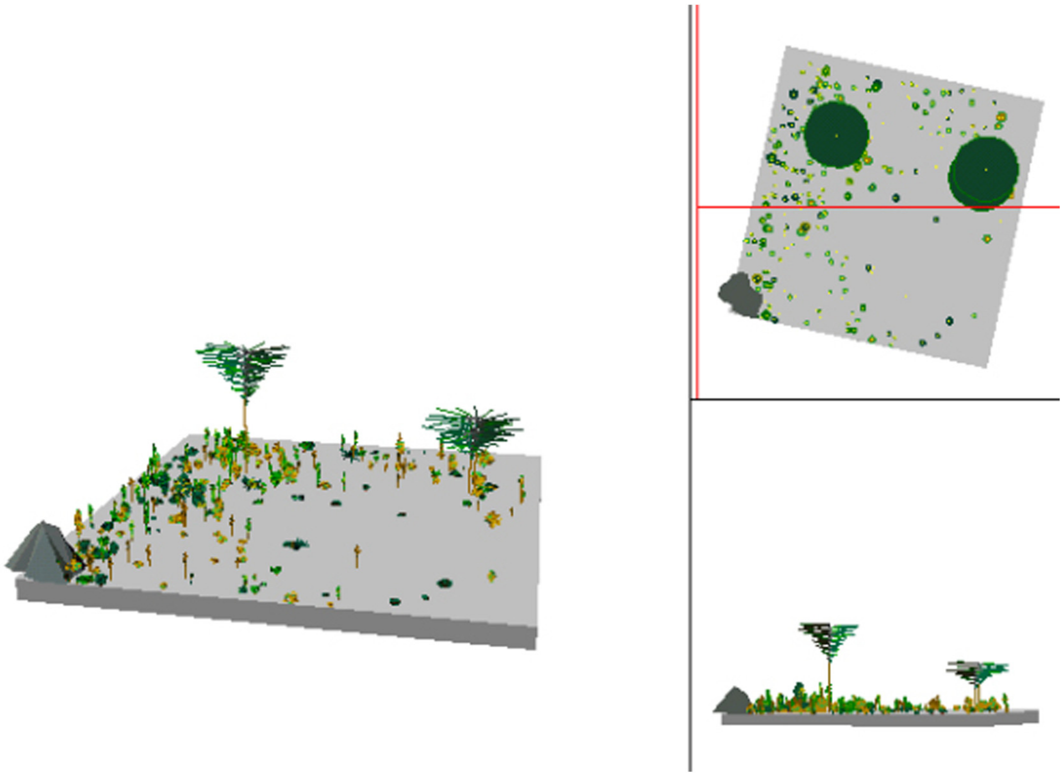

Figure 2 Scheme of the exclosure plot in 2001; North on the left side shown by red T, plotted with Stand Visualization System (SVS) software.

Table 2 Number of woody species in Firmihin exclosure plot (E = endemic).

Species	Total number	Nr of individuals in entire period	Nr in 2000	Nr in 2001	Nr in 2002	Nr in 2003	Nr in 2004
Aerva lanata	18	7	11	11	14	15	14
Asparagus africanus	10	4	5	6	8	9	7
Barleria tetracantha E	28	8	11	16	22	19	24
Carphalea obovata E	2	1	1	1	1	1	2
Commicarpus heimerlii E	6	5	6	6	5	5	5
Croton socotranus E	7	7	7	7	7	7	7
Cryptolepis intricata E	34	30	31	32	33	32	33
Dracaena cinnabari E	7	3	3	3	3	4	6
Euphorbia schimperii	1	1	1	1	1	1	1
Ficus cordata	1	0	0	0	1	1	1
Ficus vasta	1	1	1	1	1	1	1
Flueggea leucopyrus	10	9	9	9	9	9	10
Grewia erythraea	9	5	5	6	7	9	9
Heliotropium nigricans E	8	5	7	7	8	6	6
Jatropha unicostata E	65	38	46	42	43	58	46
Lycium sokotranum E	72	58	70	72	71	61	58
Ochradenus socotranus E	5	3	3	4	5	4	4
Rhus thyrsiflora E	1	1	1	1	1	1	1
Solanum incanum	3	3	3	3	3	3	3
Trichocalyx orbiculatus E	67	61	64	64	64	61	63
Withania riebeckii E	24	8	22	17	14	10	10
Ziziphus spina-christi	3	3	3	3	3	3	3
Total	382	261	310	312	324	320	314

Table 3 Mean height of woody plants (cm) in individual years (with at least 4 individuals surviving all 5 years).

Species	Nr of ind.	Min (cm)	Max (cm)	Avg 2000 (s.d.)	Avg 2001 (s.d.)	Avg 2002 (s.d.)	Avg 2003 (s.d.)	Avg 2004 (s.d.)	Avg 5 years increment (s.d.)	Avg height in control plot/nr/s.d.
Aerva lanata	7	15	80	24.3 (±4.5)	27.3 (±3.8)	43.7 (±8.3)	48.9 (±5.8)	50.4 (±5.6)	26.1 (±2.5)	18/4/±4.4
Asparagus africanus	4	14	38	21.0 (±2.1)	24.5 (±3.6)	26.5 (±4.3)	27.3 (±3.0)	27.0 (±3.0)	6.0 (±1.2)	19/1
Barleria tetracantha	8	10	54	16.9 (±3.0)	23.1 (±4.0)	30.4 (±5.2)	30.6 (±4.3)	32.0 (±5.4)	15.1 (±3.9)	10.2/18/±1.4
Commicarpus heimerlii	5	20	75	36.0 (±10.4)	40.6 (±9.0)	42.4 (±8.5)	48.2 (±8.2)	53.2 (±10.6)	17.2 (±10.7)	39/2/±0.5
Croton socotranus	7	30	230	79.3 (±29.8)	103.3 (±26.4)	114.6 (±24.3)	129.3 (±22.0)	131.1 (±22.5)	45.3 (±9.2)	92.1/21/±15.6
Cryptolepis intricata	30	10	118	32.4 (±13.5)	37.9 (±11.5)	42.7 (±11.4)	53.0 (±12.1)	53.2 (±11.3)	20.8 (±12.1)	25.4/21/±14.7
Flueggea leucopyrus	9	13	230	60.9 (±23.2)	63.8 (±25.0)	76.2 (±27.9)	103.8 (±24.6)	98.2 (±24.5)	37.3 (±13.2)	10/2/±1.5
Grewia erythraea	5	10	35	14.0 (±4.0)	14.0 (±4.0)	19.0 (±4.3)	24.2 (±2.6)	21.0 (±2.5)	7.0 (±4.5)	8.3/4/±1.1
Heliotropium nigricans	5	10	60	20.0 (±6.9)	25.0 (±6.8)	29.8 (±7.6)	38.4 (±8.1)	33.8 (±7.2)	13.8 (±2.5)	Not recorded
Jatropha unicostata	38	10	261	131.0 (±26.8)	131.9 (±27.2)	136.3 (±28.0)	142.6 (±27.0)	142.6 (±27.2)	11.6 (±5.8)	Not recorded
Lycium socotranum	58	15	240	75.4 (±22.7)	80.5 (±23.0)	85.3 (±23.8)	86.5 (±24.4)	88.4 (±24.1)	13.0 (±9.0)	74.8/78/±22.0
Trichocalyx orbiculatus	61	10	320	117.6 (±24.7)	145.4 (±28.3)	154.0 (±28.5)	166.9 (±28.0)	165.1 (±27.6)	47.5 (±20.9)	91/34/±28.5
Withania riebeckii	8	10	98	55.6 (±11.8)	58.3 (±13.4)	61.8 (±12.8)	58.8 (±11.9)	53.8 (±12.1)	−1.9 (±5.5)	Not recorded

part of the plot, specifically in squares 3–7, 12 and 50–56. In those squares, less than 1 m^2 corresponded to one woody species. In contrast, the following squares had no woody vegetation: 1, 17, 22–24, 30–31, 37–38, 71 and 73.

In 2004, the measurement of the woody vegetation was repeated for a fifth year. The growth of ‘‘bonsai-shaped’’ forms due to continuous grazing disturbance by nibbling (e.g., *C. intricata*, *F. leucopyrus*, *T. orbiculatus*) was evident (Table 3). These species demonstrated relatively rapid increments. Grazing can initially stimulate rapid growth in several of these species. Subsequently, it is probable that the growth increment becomes less rapid.

3.2. Tree planting experiment

From the three sets of ten planted seedlings every-year between 2001 and 2003, those from within the exclosure showed increasing survival rate. In all, 2 of 10 seedlings (20%) survived in the first year, 3 of 12 seedlings (25%) in the second year and 8 of 10 seedlings (80%) in the third year.

Outside the exclosure, neither seedlings nor their leave remnants were found.

3.3. Direct seed sowing experiment

Even after five years, no seedlings germinated from the 2 × 200 seeds sown in the experiment (inside and outside exclosure), in spite of the fact that the germination rate of *D. cinnabari* can be relatively high (Beyhl, 1996; Petroncini, 2000; Adolt, 2001). In the last year of the experiment, however, 4 wild seedlings were found under adult *Dracaena* trees in the exclosure site. These seedlings were located 3–6 m from the places where the seeds were sown.

4. Discussion

4.1. Woody vegetation development

The most interesting finding in the exclosure area after nearly five years of study was the presence of relatively constant number of woody species, in contrast to the massive overgrowth of the area by grasses. On the basis of Central European but also other conditions, it would be expected that after a relatively short period of grazing control, various species would begin to regenerate in the area (e.g., Van Uytvanck et al., 2010; Prevosto et al., 2011; Vojta and Drhovská, 2012; Bebawi et al., 2013). However, the number of woody species within the exclosure remained nearly the same. A total of 312 individuals of woody plant species were present in the exclosure at the beginning of the experiment; at the end, 316 individuals were present. Fifty of the individuals originally present died during the experiment, and 54 new individuals appeared. Most likely, most of these new individuals had grown from seeds.

It is possible that succession on areas used extensively by transhuman pastoralists for a long time proceeds much more slowly in arid regions than in areas with higher amounts of annual precipitation (i.e., Muchiru et al., 2009). Whole Firmihin exclosure site was quite rapidly overgrown by herbaceous plants, especially plants of the *Poaceae* family (*Cenchrus ciliaris* represented the majority of the biomass). In dense grass cover, certain (primarily unpalatable) woody plants are unable to survive, e.g., *W. riebeckii* or *H. nigricans*, as already mentioned. According to several authors (e.g., Skarpe, 1990), the heavy grazing of grasses by cattle will produce an increase in shrub density. On the experimental plot, the aboveground biomass of grasses reached as much as 270 g/m^2, i.e., 2.7 t/ha (in dry biomass). In contrast, the dry biomass in an arid region in NE Niger with less than 150 mm of precipitation per year reached 0.24–0.41 t/ha (Chaibou et al., 2011). *C. ciliaris* under *Acacia tortilis* in India (where the annual precipitation reaches 915.55 mm) produced 3.72 t/ha of dry biomass (Mishra et al., 2010).

The distribution of vegetation on the experimental plot indicated that various microclimatic conditions were present. The umbrella-shaped crown of the dragon's blood trees (3 trees present in the exclosure site), supported by its very dense rosettes of leaves, evidently facilitates the development of plants and seedlings in the shade of the trees. According to experimental measurements, the differences between temperature/air humidity on full sun and under the *Dracaena* crown during 8 days in April 2004 achieved nearly 1.5 °C in air temperature and more than 3% in air humidity. These conditions are more convenient for plant growth than those associated with full sun (e.g., Rejzek et al., 2012; Schöb et al., 2013). During the regular seasonal occurrence of fog, the *D. cinnabari* crowns intercept moisture from the fog, and horizontal precipitation subsequently falls from the branches to the ground. Experiments from June 2009 show a great contribution of horizontal precipitation; during a night (ie., 12 h) precipitation achieved 0.4–5.0 mm under the crown comparing to zero outside the tree crown (M. Cermak and M. Culek, unpublished data). Thus, soil water potential under the crowns naturally decreases, and the shade of the crowns decreases the evaporation to levels that are lower than those in the surrounding environment (Fig. 3).

The growth dynamics of species occurring in the areas within and outside the exclosure plot shows quite unambiguously that the elimination of trees and shrubs by grazing is the important factor affecting the plants of the island (cf. studies in similar climatic conditions by, e.g., Al-Rowaily et al., 2015; Mekuria et al., 2007; Skarpe, 2000; Vetaas et al., 2012 or Yayneshet et al., 2009).

For example, the mean height of *A. lanata* was 18 cm outside the exclosure, whereas the mean height was 24.3 cm inside the exclosure in 2000 (five months after the construction of the fence); in 2004, the height reached 50.4 cm. The mean height of 34 individuals of *T. orbiculatus* was 91 cm outside the fenced area, whereas the mean height of 61 individuals inside the fenced area was 117.6 cm in 2000 and 165.1 cm in 2004. Thus, the effect of grazing on the regeneration of tree and shrub species (with the exception of poisonous and/or unpalatable species) is quite evident. Although the occurrence of grazing is related to the arrival of the first people on the island approximately 3000 years ago, the growing human population and the associated livestock population currently cause increased fuel consumption and are particularly implicated in the decline of the original vegetation communities (Van Damme and Banfield, 2011).

Recapitulating presumption that exclosure establishment triggers fast woody species regeneration and growth (first hypothesis) – this has not been confirmed in full for all of the recorded species. Some woody species show positive response to formation of exclosures while others – especially those unpalatable – are on contrary supported by ruminants selective grazing, having even troubles to survive in laden plant competition within exclosures.

Figure 3 Animals and shrubs profiting from shade of adult *Dracaena* tree.

4.2. Tree planting experiments

The increased survival rate of the planted *D. cinnabari* seedlings (20%, 25% and 80%) can be explained not only by differences among years in climatic conditions but also, most likely, by the degree of development of the planted material. In the first year, 2001, 10 one-year-old seedlings were planted, and seedlings of the same age were transported to the Ras-Ayre acclimatisation nursery. Ten of the seedlings from the nursery were planted in the exclosure after one year, and 10 more were planted after two years. Two-year-old plants were planted in the second year, and three-year-old plants were planted in the third year.

The hypothesis of a relationship between seedling survival and the degree of development of the planted material is supported by the team work and observations from the Ras-Ayre reforestation area, where 1 ha of fenced area was planted in May 2006 with three/four/five-year-old *D. cinnabari* seedlings. A total of 715 plants were planted, and some of them were irregularly irrigated. After three years, 678 survived, and 497 were still alive after six years. In September 2009, 203 seedlings were in excellent condition, 331 in good condition and 144 in poor condition; in March 2012 (before main rain season), 72 were in excellent condition, 177 in good condition and 248 in poor condition.

The surprising survival of seedlings can be considered to be a very important result. The first seedlings were planted into soil with a low water potential (water-saturated) and survived for long periods of drought, when rain occurred only three times per year, i.e., immediately after planting at the end of September 2001 (6 mm) and then in May 2002 (12 mm) and June 2002 (19 mm); the seedlings were not watered. Moreover, other planted seedlings survived after the long period of drought, when rain occurred at the end of September 2002 (302 mm, Habrova, 2007) and moderate precipitation most likely occurred in December 2002 and again in May 2003. In addition to this precisely measured precipitation (automatic Czech meteorological station "μEMSet 99" was installed in

2000 directly into the exclosure), only horizontal dew and mist occurred between May and September.

All seedlings outplanted in June 2003 survived until December 2003. Approximately one-quarter of the seedlings died by April 2004. However, the factors involved in this mortality cannot be determined by non-destructive methods after such a short period. If a seedling is dying, the oldest leaves are the first to turn yellow. The young leaves hidden within the dead leaves are the last to turn yellow. Moreover, the leaves are connected to the rosette by vascular bundles for a long time after their death. On the basis of experiments with *D. cinnabari* seedlings raised in greenhouses in Europe, it has been shown that a plant that is nearly dead rapidly forms a new root system and new leaves after irrigation if at least three partially living leaves remain. For these reasons, it was not possible to determine the exact number of dead plants after four months in April 2004. Although it is obviously too early to reach positive conclusions, it is possible to state that older seedlings, particularly those with a well-developed root system, show a far greater potential of survival under the extreme conditions of a long-term drought. The experimental planting of seedlings outside the fenced plot in 2003 showed that grazing by goats in *D. cinnabari* woodlands absolutely prevents the natural regeneration in these forests. If a plant dies spontaneously, remnants of its leaves can be found for a relatively long time. No remnants at all were found from the seedlings outplanted outside the fence. Unfortunately, it was not possible to observe the further development of the planted seedlings inside the exclosure, as the fence was partially damaged in 2005 prior to our next visit, and all the seedlings were obviously grazed by ruminants as well as all planted seedlings outside the exclosure.

The second hypothesis - answering the question if *D. cinnabari* seedlings will survive long drought periods inside the protected exclosure - has been thus confirmed. The most important result is that older seedlings (3–5 years), particularly those with a well-developed root system, show a far greater potential to survive under the extreme conditions of long-term drought.

4.3. Direct seed sowing experiment

No new seedlings appeared from the sown seeds during the period 2000–2004 neither inside nor outside the exclosure. Observations based on greenhouse conditions show that considerably delayed germination of *D. cinnabari* seeds occurs (Adolt, 2001). Under laboratory conditions, seeds commonly germinate even after ten years of storage – nine-year-old seeds show a germination rate of approximately 40%.

In the final years of the experiment, four seeds germinated in places other than those in which the seeds were sown. All of these seedlings were located in the grass under the crowns of mature trees. In terms of the microclimate suitable for the germination of seeds, the humus layer, which is totally absent from the grazed areas, is, most likely, very important. The above-ground biomass, that was not removed (grazed) inside the exclosure, resulted in the formation and deposition of dead biomass and, thus, in the creation of a humus layer.

In this context, it is also necessary to mention the germination of seeds in a mountain region, where seeds readily germinate during precipitation-rich seasons, particularly under the crowns of mature trees or under bush cover where the semi-decomposed litter layer accumulates. However, seedlings at such sites are a sought-after delicacy for local cattle, as documented by their remnants observed between tufts of grass. Dragon's blood trees germinate even in inaccessible localities, on steep slopes and in rock fissures, where they are beyond the reach of intensive grazing. In a 4 ha fenced area owned by the former Yemeni president in Dixam Plateau (approximately 900 m a.s.l.), we found 286 one-year-old seedlings and 13 two-year-old seedlings under 15 adult DC trees in 2009.

Bringing together the above mentioned discussion to some finale, one can confess that last of the hypothesis – testing if DC seeds germinate and survive better during rains – has not been confirmed. Presence of a humus layer – which is totally absent from the grazed areas – is likely the most important factor, nevertheless all range of microclimatic factors should be considered and investigated.

5. Conclusions

The long-term investigation of vegetation dynamics in Socotran *D. cinnabari* forests that are unique worldwide, is decisive for permanent and sound conservation management. Presented findings can nevertheless shed some more light also on functioning of arid lands in general, bringing new perspective into the understanding of interactions between transhuman pastoralists and vegetation dynamics. To support the process of regeneration of the naturally occurring and ruminant sensitive woody species, a suitable approach could be to establish permanent fenced plots with mature trees inside. However, wider range of microclimatic factors has to be considered and investigated while trying to reforest *Dracaena* trees. It is thus feasible to sow seeds under the protection of shrubs or grass layer where the number of trees is already low (on Socotra, e.g., in Dixam, Kleem and Shibhon plateaux). Another and probably more effective possibility is direct planting of well-developed (3–5 years old) seedlings into protected areas. Seedlings planted in this way shall be supported by individual protection. These findings are applicable also for other semi-arid regions, especially in woodland management of other *Dracaena* tree species e.g. *Dracaena serrulata* in Oman, Saudi Arabia and continental Yemen, *D. draco* and *D. tamaranae* in Macaronesia, *D. ombet* and *D. schizantha* in East Africa, *D. draco* ssp. *ajgal* in Morocco etc., Although, the method of individual seedling support and protection involves substantial financial and time costs. Naturally, it is necessary to consider the site suitability, provenance of the plants and seeds used. Practical suggestions to conserve natural forest/woodland biotopes via proved forestry measures in similar biomes should be realised on the ground. Results of this study, supported by presented findings from sites with and without grazing, shall reinforce the idea of mandatory grazing restrictions to allow the conservation and/or existence of the designated World Heritage Sites for future generations.

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